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Backward Wave Coupler for Sub-millimeter Waves in a
Traveling Wave Tube

Field of the Invention

This invention was made with United States government support under Grant NAS3-01014 from National Aeronautics and Space Administration. The United States Government has certain rights in this invention.

The present invention is related to coupling structures for microwave traveling wave tubes. More particularly, it is related to a structure for coupling traveling waves into and out of a traveling wave tube, including the class of traveling wave tubes operating in the sub-millimeter wavelength region.

Background of the Invention

A Traveling-Wave Tube (TWT) may act as an amplifier or an oscillator for Radio Frequencies (RF). This is

1 accomplished through the interaction of an electron beam and
2 an RF circuit known as a slow wave structure, where the RF
3 wave velocity as it travels down the circuit is much less
4 than that of light in a vacuum. As the electron beam
5 travels down this interaction region, an energy exchange
6 takes place between the electrons and the RF circuit wave.
7 When a traveling wave tube is configured as an amplifier, RF
8 energy is applied to an input port, and the interaction
9 between the RF and the electron beam produces power gain,
10 and the amplified signal is removed from an output port.
11 When a traveling wave tube as an oscillator, at some
12 frequency there is sufficient internal RF coupling through
13 the gain element at a particular frequency to enable
14 oscillation at that frequency. Backward wave devices have
15 the property that this oscillation frequency can be
16 controlled by the voltage applied between the cathode and
17 anode of the electron gun.

18 Figure 1 shows the three basic components to any TWT or
19 linear beam device. A TWT includes an electron gun which has
20 a thermionic or field emission cathode 108, a slow wave
21 circuit shown as input coupler 116, output couplers shown as
22 backward wave couplers 118 and 120, and a collector shown as
23 112. The electron gun emits electrons and the application
24 of a high differential voltage optionally combined with a
25 magnetic focusing circuit (not shown), the electrons travel

1 down electron beam 114 tunnel terminating in collector 112.
2 The voltage applied to the cathode may range in value from
3 several hundred to several hundreds of thousands of volts.
4 The slow wave structure 116 which is shown generically
5 coupled to electron beam 114 may couple RF energy into the
6 electron beam 114, or it may provide a source of oscillation
7 coupled to electron beam 114, or it may act as an amplifier
8 whereby it includes an input port (not shown) and has the
9 characteristic of a bandpass filter for RF waves in the
10 region of interest. Over a particular band of frequencies,
11 which can range as high as two or more octaves, the slow
12 wave structures 118 and 120 may provide a frequency transfer
13 function for the RF energy traveling through them. There are
14 numerous types of slow wave structures including helical,
15 coupled-cavity, and ring-and-bar circuits. The frequency at
16 which the device operates is determined by the geometry and
17 size of the slow wave structures 116, 118, and 120. In a
18 backward wave device, the slow wave structures 118 and 120
19 cause RF energy in the circuit to counter-propagate, or
20 propagate toward the electron gun to an output port, as will
21 be explained later. After the RF energy has been coupled
22 into and extracted from the electron beam using slow wave
23 structures such as backward wave couplers 118 and 120, the
24 beam enters a region known as the collector 112, which
25 collects the spent beam. There are many collector

1 configurations used in linear beam devices. Some of these
2 include single-stage grounded collectors and multiple stage
3 collectors. The driving concept behind the selection of
4 collector used is efficiency and power supply
5 considerations.

6 A backward wave device, whether it be an amplifier or
7 an oscillator, is a type of traveling wave device which
8 includes a slow wave structure which causes the phase
9 velocity of a forward moving wave to have a negative value,
10 so that it travels in a direction counter-propagating
11 (opposite the direction of) the electron beam 114.

12 Figure 2 shows a ω - β curve for an electron beam
13 interacting with a slow wave structure such as backward wave
14 coupler 120 of figure 1, where the x axis 105 is the wave
15 number, which for corrugated structures are normalized to
16 $k*d$, where:

17 k is the wave number, or $1/\lambda$, and λ is the wavelength
18 of interest;

19 d is the depth 123 of the corrugations shown in figure
20 1;

21 and the period of pitch p 121 of figure 1 is constant.
22 The y axis of the graph shows the upper cutoff frequency,
23 for a structure, where

24 f_{cutoff} is proportional to $1/d*c$

1 where

2 d = depth of corrugation, as before,

3 c = velocity of light.

4 Curve 102 is the electron beam line, the slope of which
5 indicates the electron beam velocity as electrons leave the
6 cathode and travel down the beam tunnel, and the slope of
7 this line 102 increases with larger voltage applied by
8 cathode 108 in figure 1. The functional characteristics of
9 a slow wave structure having a fixed pitch p 121 from figure
10 1 and varying depth d 123 from figure 1 is shown as curve
11 106a, 106b, and 106c, which for corrugation structures is
12 governed by the parameters p 121 and d 123 both from figure
13 1. Smaller values of d yield a higher cutoff frequency, and
14 larger values of d result in a lower cutoff frequency.
15 Operation of the RF slow wave structure with a large cathode
16 electron acceleration voltage results in an intersection
17 point between the electron beam line 102 and the slow wave
18 structure curve 106a, 106b, or 106c in the region 0 to π ,
19 and the device operates as a forward wave device. A
20 reduction of the cathode electron acceleration voltage
21 results in a lower slope of the electron beam line 102, and
22 the electron beam line 102 intersects the RF slow wave
23 structure characteristic curve at point 104. Operating
24 point 104 is shown in the region from π to 2π known as the
25 backward wave region, and the RF waves are counter-

1 propagating with the electron beam, where the RF is
2 propagating in a direction opposite the direction of the
3 electron beam. For a given slow wave structure geometry, as
4 the electron beam voltage is slightly increased, curve 102
5 has a greater slope, and intersection point 104 supports at
6 a higher operating frequency F_1 101. For given operating
7 point 104, traveling waves can be supported up to a
8 frequency F_1 101 where the corrugation depth $d=80u$, as shown
9 in the present example. If the traveling waves experience a
10 change in corrugation depth to $100u$ as shown in
11 characteristic curve 106c, the slow wave structure will no
12 longer support traveling waves at this frequency, and the
13 waves will be reflected in the region of the discontinuous
14 interface where the depth d is increased. The curves 106a,
15 106b, and 106c are normalized to wave number in the x axis
16 and show the relationship between corrugation depth and the
17 maximum RF frequency the slow structure can support. The
18 curves of figure 2 are ordinarily computed using numerical
19 techniques for a specific structure. In the present
20 example, curves of figure 2 were calculated for the case
21 where the corrugation pitch $p = 50u$ and the width of the
22 individual structures is $20u$ for a variety of depths d 123
23 (from figure 1) ranging from $40u$ to $100u$. These curves, in
24 conjunction with the electron beam line 102 enable the
25 design of reflecting structures for use in forward or

1 backward wave regions. One of the problems with devices
2 that operate in backward wave regions is the inefficiency of
3 coupling between the slow wave structure and the output
4 waveguide.

5 Figure 3 shows a backward wave structure from the
6 unpublished design of a Russian-designed microwave tube
7 available commercially in Russia. An electron beam 135
8 travels from a beam tunnel entrance 130 through a beam
9 shaper 132 to a beam tunnel exit 138, and beam shaper 132 is
10 at the same height as corrugations 136 having a depth d in
11 accordance with the characteristics of figures 1 and 2.
12 Additionally, the beam shaper includes a series of slots
13 parallel to the electron beam 135 axis which cause the
14 electron beam 135 to travel over and around the corrugations
15 which are perpendicular to the electron beam 135. This dual
16 corrugation produces pin structures known as pintles 136
17 which have a depth d and pitch p perpendicular to the axis
18 of the electron beam 135. These pintles 136 include
19 longitudinal slots which allow the electron beam to surround
20 the pintles 136, and therefore interact with the them in an
21 enhanced manner. Section z-z through the beam shaper 132 of
22 figure 3 is shown as figure 3a showing the slots in the beam
23 shaper 132 and the electron beam 135 forming around these
24 slots. These slots continue in the pintles 136 shown in
25 section view a-a in figure 3a with electron beam 135. The

1 cross section through pintles 136 of section b-b is shown in
2 figure 3b, which effectively shows a top view of the pintles
3 136 and also pintles 134 from the sloping region of figure
4 3. The pintles 136 are physically small and not well
5 thermally coupled to substrate 131 in figure 3, and an
6 imperfectly aligned electron beam 135 directly impinging on
7 these pintles would cause them to overheat and melt. By
8 machining the beam shaper 132 to the same height as the
9 pintles 136, and including slots in beam shaper 132 which
10 continue through pintles 134 and 136, the shaper 132 is able
11 to very closely couple the electron beam 135 with the
12 pintles, tightly coupling the tops and sides of the pintles
13 136 with the electron beam 135 as shown in figure 3a. The
14 pintles are therefore shielded from overheating due to
15 direct exposure to a misaligned electron beam by the beam
16 shaper 132, which conducts excess heat into the slow wave
17 structure body 131 from figure 3. The operation of the
18 backward wave coupler of figure 3 includes the reflection of
19 RF energy carried in the beam by sloping structure 134,
20 whereby reflected wave energy is coupled into the output
21 aperture 140. In the unpublished RF device of figure 3, the
22 output port 140 is placed between a row of pintles in the
23 sloped region 134. Fabrication of the device shown in
24 figure 3 for use in sub-millimeter wavelengths is very
25 difficult, as the features are on the order of 10s of

1 microns, and the sloping section 134 must be completed prior
2 to the pintle fabrication. The best method for pintle
3 feature manufacturing is electro-discharge machining, which
4 is best done using substantially planar surfaces, as opposed
5 to the sloping surface 134.

6 In prior art devices such as in U.S. Patent No.
7 4,263,566 by Guenard and shown in figure 1 structures 118
8 and 120, the slow wave structures are corrugated in one
9 dimension only such that the cross section of figure 1 is
10 correct for any section through the slow wave structure.
11 Similarly, the slow wave structure described in U.S. Patent
12 No. 4,149,107 by Guenard comprises 1-dimensional slots as
13 shown. In the Russian device of figure 3, the corrugations
14 perpendicular to the electron beam are supplemented by slots
15 parallel to the electron beam which produce structures
16 referred to as pintles, which are a plurality of pins spaced
17 on regular intervals, typically 10-20 pintles per
18 wavelength, in accordance with the desired frequency
19 performance as described in figure 2. While backward wave
20 devices enable operation over a wide range of frequencies
21 tunable by changing the electron beam voltage, backward wave
22 devices suffer from inefficient coupling of RF energy to the
23 output port and the use of pintles increases the efficiency
24 of this coupling.

25

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2 Objects of the Invention

3 A first object of the invention is a slow wave
4 structure for reflecting RF energy either co-propagating
5 with (traveling in the same direction) an electron beam or
6 counter-propagating with (traveling in the opposite
7 direction) an electron beam.

8 A second object of the invention is a slow wave
9 structure having a reflector, said reflector causing RF
10 energy counter-propagating in an electron beam to co-
11 propagate to an output port which is spaced a half
12 wavelength from the reflector.

13 A third object of the invention is a slow wave
14 structure comprising a plurality of pins placed in a
15 substrate, the depth of said pins changing a half wavelength
16 from an output port.

17 A fourth object of the invention is a slow wave
18 structure comprising a plurality of pins forming a
19 substantially planar surface, said plurality of pins located
20 on a substrate, the depth of said pins undergoing a step
21 change a half wavelength from an output port.

22 A fifth object of the invention is a slow wave
23 structure comprising a plurality of pins forming a
24 substantially planar surface, said pins located on a
25 substrate, the depth of said pins undergoing a plurality of

1 step changes, each said step change being a distance of half
2 a wavelength from an output port.

3 A fifth object of the invention is a slow wave
4 structure for an electron beam having an axis, said slow
5 wave structure having, in sequence, a electron beam
6 entrance, an optional beam shaper, a reflection region, a
7 half wave region, an RF output port, a gain region, and an
8 electron beam exit, the slow wave structure having a
9 substrate which includes a plurality of corrugations
10 perpendicular to said axis, said corrugations having a first
11 depth in a region from said beam exit to a half wavelength
12 past the RF output port, and a second depth thereafter, the
13 pins having a substrate end and an unsupported end which is
14 substantially parallel to said electron beam.

15 A sixth object of the invention is a slow wave
16 structure for an electron beam having an axis, said slow
17 wave structure having a substrate, said substrate having
18 corrugations, said corrugations having one end forming a
19 substantially planar surface, said slow wave structure
20 including, in sequence, an electron beam entrance, a beam
21 shaper having a surface substantially planar with said
22 corrugations, a reflection region having said corrugations
23 at a first depth, a half wavelength region having
24 corrugations at a second depth, an RF output port located a
25 half wavelength from said corrugations changing from said

1 first depth to said second depth, a gain region having
2 corrugations at said second depth, and a electron beam exit.

3 A seventh object of the invention is a slow wave
4 structure for an electron beam having an axis, said slow
5 wave structure including, in sequence, an electron beam
6 entrance, a beam shaper having a plurality of slots parallel
7 to said electron beam axis, a plurality of pins having a
8 first depth below said beam shaper and attached to said
9 substrate, a plurality of pins having a second depth below
10 said beam shaper and attached to said substrate, an RF port
11 located a half wavelength from the change from said pin
12 first depth to said pin second depth, a plurality of pins
13 having said second depth and attached to said substrate,
14 and a an electron beam exit.

15

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17 Summary of the Invention

18 A slow wave structure for a backward wave traveling
19 wave tube comprises a substrate having a plurality of pins,
20 known as pintles. The pintles are elongate cantilever
21 structures interacting with an electron beam traveling in a
22 beam tunnel. The pintles have one end mounted to and
23 perpendicular to the substrate, and an opposing cantilever
24 end. The pintles are small in comparison to the physical
25 wavelength of the electromagnetic wave counter-propagating

1 with the electron beam. The cantilever end of the pintles
2 forms a substantially planar surface in the region of the
3 electron beam, and the substrate supporting the pintles and
4 located below the electron beam includes an exit aperture
5 and at least one step change located a half wavelength from
6 the exit aperture on the electron beam entrance side of the
7 beam tunnel. In backwards wave mode, Radio frequency (RF)
8 energy counter-propagating with the electron beam is
9 reflected by the change in height of the pintles, and is
10 coupled into the output port which is located half a
11 wavelength away from the step change in pintle height. For
12 broadband devices, there may be a plurality of step changes
13 for a plurality of wavelengths, each step change located a
14 half wavelength at some frequency of operation from the exit
15 aperture. The slow wave structure may also include a beam
16 shaper, comprising a ramp perpendicular to the electron beam
17 axis, positioned near the electron beam entrance, and having
18 a plurality of slots parallel to the electron beam axis,
19 such that the slots and pintles form common channels for the
20 electron beam.

21 22 23 Brief Description of the Drawings

24 Figure 1 is a section view of a prior art traveling
25 wave tube.

1 Figure 2 is an ω - β graph showing the maximum operating
2 frequency of a microwave tube as a function of electron
3 voltage versus pin depth.

4 Figure 3 shows a section view of a prior art backwards
5 wave coupler.

6 Figure 3a is a section view through section a-a of
7 figure 3.

8 Figure 3b is a section view through section b-b of
9 figure 3.

10 Figure 4 shows a section view of a backward wave
11 coupler according to the present invention.

12 Figure 5a shows the detail of the pintles near the
13 waveguide of figure 4.

14 Figures 5b and 5c show a section view of the pintles in
15 the reflection region, the beam shaper region, and the half
16 wave region of figure 4.

17 Figure 6 shows a section view of a backward wave
18 coupler according to the present invention.

19 Figure 7 shows a traveling wave device configured as an
20 oscillator.

21 Figure 8 shows a traveling wave device configured as an
22 amplifier.

23
24
25 Detailed Description of the Invention

1 Figure 4 shows the side view of a backward wave coupler
2 150 for a traveling wave tube, which is defined in a
3 coordinate system y and z axis as shown, and an x axis
4 (shown in figures 5b and 5c) perpendicular to the y and z
5 axis. An electron beam 152 is emitted from a cathode (not
6 shown) and enters beam tunnel entrance 162, where it travels
7 over beam shaper 153. This beam shaper 153 may have a
8 plurality of slots parallel to the axis of electron beam 152
9 and over and around a plurality of pintles 154, which
10 comprise corrugations having a pitch p, a width w, a depth
11 d1 as shown in figure 5a, and may also include slots
12 substantially aligned with the slots of beam shaper 153, and
13 parallel to the axis of electron beam 152. The electron
14 beam 152 may include counter-propagating RF at a wavelength
15 λ , and the pintles 154 are spaced at less than 0.1λ in the z
16 and optionally x directions. The pintle surface plane 166
17 is planar with a surface of the beam shaper 153 and a z-x
18 plane below the electron beam 152. The pintles may follow
19 the shape of the electron beam 152 to enable maximal
20 coupling between the pintles and the RF carried in the
21 electron beam 152. The pintles 154 are cut to a depth 168
22 in a half wavelength region having a distance of a multiple
23 of a half wavelength ($\lambda/2$) 157 on the beam tunnel entrance
24 162 side of output aperture 158. The half wavelength
25 distance 157 may also be any integer multiples of wavelength

1 such as $(n+1)\lambda/2$ where n is an integer > 0 . In the
2 reflection region beyond the half wavelength separation
3 distance 157, the pintles change depth 170 while maintaining
4 the same pintle surface plane 166 as the pintles 154 and
5 beam shaper 153. This change in substrate 151 to depth 170
6 causes RF energy counter-propagating with the electron beam
7 152 to reflect and co-propagate towards the exit aperture
8 158, where the counter-propagating RF energy and reflected
9 co-propagating RF energy add in phase to a maximum level in
10 the region of output aperture 158, and couple out. The
11 pintles 154 are shown having a regular period leading up to
12 the output aperture in gain section 161 and following the
13 output aperture 158 in half wave section 157 and reflection
14 section 159. It has been found that removing one or more
15 rows of pintles in the region of the output aperture 158
16 increases the coupling of reflected RF into output aperture
17 158. This is shown in figure 5a, which is a detailed view
18 of figure 4 showing the removed rows of pintles 155 in
19 phantom outline with the RF output aperture 158 centered in
20 the resulting gap between pintles 154.

21 Increased interaction between the RF counter-
22 propagating in the electron beam 152 and the corrugations
23 154 occurs when slots parallel to the electron beam axis are
24 cut into the beam shaper 153 and corrugations 154, resulting
25 in a slotted beam shaper 153 and pintle structures 154.

1 When slots parallel to the electron beam 152 axis are added
2 to enhance coupling between the counter-propagating RF and
3 corrugations 154, figure 5b section e-e shows the resulting
4 slotted beam shaper 153. Figure 5b also shows section c-c
5 through figure 4 in the x-y plane, showing electron beam
6 152, pintles 160 at uniform height 166 and a second depth
7 168, and figure 5c shows the same view through section d-d
8 of figure 4 where the pintles 160 are cut to a first depth
9 170 in the reflection region 159 of substrate 151 from
10 figure 4.

11 The structure of figure 4 can be used as an input port
12 in the forward wave mode by coupling power into input port
13 158, which co-propagates through gain section 161. It is
14 also possible to use the slow wave structure of figure 4 as
15 an output port in forward wave mode by reversing the beam
16 direction such that the electron beam enters at 164 and
17 exits at 162, and the beam shaper is placed at the same
18 height 166, but at 164. In this manner, forward waves co-
19 propagating with the electron beam enter at 164, travel
20 through gain section 161 and co-propagate to exit aperture
21 158, where they combine with reflected counter-propagating
22 waves from reflection region 159. As described earlier,
23 higher electron beam velocities are used for forward wave
24 devices compared to the backward wave devices description of
25 figure 4.

1 Figure 6 shows a multi-wavelength reflection slow wave
2 structure 180. Electron beam 184 travels down a beam tunnel
3 having in sequence a beam tunnel entrance 182, a beam shaper
4 181, a plurality of elongate pintles 185 having one end
5 attached to a substrate 181 and an opposing end which is in
6 proximity to the electron beam 184, the plurality of pintles
7 formed into a reflection region comprising a plurality of
8 pintles cut to decreasing first depths 207, 206, 204, a half
9 wavelength region having the plurality of pintles cut to a
10 second depth, an output aperture 208, and a plurality of
11 pintles 185 at a second depth 202. Each change in pintle
12 depth in the reflection region is spaced a half wavelength
13 from the exit aperture 208 for a given output wavelength.
14 By selecting the particular corresponding wavelengths for
15 these depth changes in the reflection region 196, it is
16 possible to optimize the operation band of the device over a
17 wide range of wavelengths. The plurality of the opposing
18 ends of pintles 185 may be substantially planar with the
19 beam shaper 181 and substantially co-planar with the
20 electron beam 184 axis. The RF counter-propagating with the
21 electron beam 184 travels past the output aperture 208 for
22 the removal of RF energy, and the plurality of pintles 185
23 changes to a second depth 204 at a first half wavelength
24 distance 190. The pintle depth is again changed to a third
25 depth 206 at a second half wavelength distance 192, and may

1 also continue to subsequent depth 207 at additional half
2 wavelength 194. Each half wavelength distance 190, 192, 194
3 is associated with a particular half wavelength of RF
4 counter-propagating with electron beam 184 which is
5 reflected as a co-propagating RF wave to sum with the
6 counter-propagating RF wave and couple to output aperture
7 208. The half wavelength separation distances 190, 192, 194
8 may also be any integer multiples of wavelength such as
9 $(n+1)\lambda/2$ where n is an integer > 0 , as was described in
10 figure 4. As was described in figure 5a, a row or more of
11 pintles may be removed and the waveguide 208 centered in the
12 resulting gap to enhance coupling of reflected RF energy to
13 the output aperture 208.

14 The pintles 154 and 160 of figure 4, and 185 of figure 6 may
15 be made in a variety of shapes, and arranged in a variety of
16 forms. The pintles may be rectangular or circular, and they
17 may be formed by machining substrates 151, 181, or by
18 chemical etching or electro-discharge machining (EDM) of the
19 substrate, as is known in the art of machining metallic
20 substrates 151 and 181. For any of these machining
21 processes, it is desirable to have the structures formed
22 from a planar surface, as shown in the figures of the
23 present invention. The pintles 154 and 160 of figure 4, and
24 185 of figure 6 may comprise corrugations perpendicular to
25 the axis of the electron beam, or they may include slots

1 which are parallel to the axis of the electron beam, and the
2 beam shaper 153 of figure 4 and 181 of figure 6 may or may
3 not be present, depending on the accuracy of alignment of
4 the electron beam 152 of figure 4 and 184 of figure 6. In
5 general, the structures of the pintles and beam shaper are
6 formed from a planar substrate.

7 The reflector structures shown in figures 4 and 6 may
8 be combined in a variety of ways to form traveling wave tube
9 oscillators and amplifiers using forward wave region or
10 backward wave region operation, for which two examples are
11 shown in figures 7 and 8.

12 Figure 7 shows the present invention used as a tunable
13 wideband oscillator 220 in backward wave mode. A cathode
14 222 in proximity with an anode 226 has an applied voltage
15 224 which causes the cathode 222 to emit a beam of electrons
16 234 in the backward wave region of figure 2, which may be
17 focused using an external axial magnetic field (not shown),
18 as known to one skilled in the art. Slow wave structure 221
19 includes an electron beam entrance 228, a beam shaper 238
20 followed by a plurality of pintels 236 forming reflector
21 section 232 comprising a plurality of pintles of decreasing
22 depths each successively positioned one half wavelength from
23 output aperture 242 as was described in figure 6, an output
24 aperture 242, and a gain section 240. The spent electron
25 beam 234 dissipates in collector 230. RF noise in the gain

1 section 240 is amplified in counter-propagating waves, which
2 are reflected in reflector region 232 to co-propagating
3 waves which combine with the counter-propagating wave and
4 couple into output 242. The internal coupling of forward
5 and reflected waves causes an oscillation at a particular
6 frequency, which is tunable with cathode voltage 224, and
7 the reflector 232 provides for gain over a range of
8 frequencies for which the device may operate.

9 Figure 8 shows the present invention used as an forward
10 wave amplifier 260. Figure 8 shows a pair of RF reflectors
11 of figure 4 arranged in a mirror fashion as an input
12 reflector 268 and an output reflector 276. Cathode 264 in
13 conjunction with voltage source 262 and anode 266 supplies a
14 beam of electrons 280 in forward wave mode, which is shaped
15 to the height of the pintels by beam shaper 267, as before.
16 The beam shaper 267 may include slots parallel to the
17 electron beam 280 axis at the same depth as the pintels in
18 the gain section 272. Input RF energy is coupled into port
19 270, which is coupled into the beam tunnel, whereby some RF
20 energy is directly coupled co-propagating towards collector
21 278 and some RF energy is reflected by input reflector 268,
22 summing in phase with incoming energy from port 270. The RF
23 co-propagates through gain section 272, and is coupled to
24 output 274 with output reflector 276, as before. The spent
25 beam passes to collector 278. For the amplifier

1 configuration of figure 8, the voltage 262 is adjusted to a
2 voltage in the forward wave region of figure 2 about which a
3 range of wideband amplification may take place.

4 While a specific illustration for the backward wave
5 structure has been shown for the purposes of illustration,
6 it is clear that the reflector structure described in
7 figures 4 and 6 may be scaled to any wavelength, and is
8 suitable for frequencies in the thousands of Ghz (Thz)
9 region. It is clear that the reflector comprising a
10 plurality of pintles attached to a common conductive
11 substrate, the pintles having a common height substantially
12 co-planar to an electron beam, a first section which
13 includes an output port, and a reflection section located a
14 multiple of a half wavelength from the output aperture, the
15 reflection section comprising pintles at the same height as
16 the pintles of the first section, but with greater depth
17 distance to the substrate. The structure may be formed from
18 corrugations without any slots substantially co-planar to
19 the electron beam axis, or the corrugations may include
20 slots parallel to the axis of the electron beam, which may
21 improve the coupling efficiency of co-propagating and
22 counter-propagating RF to the output aperture. The
23 structures may be operated in the forward wave region with
24 the RF co-propagating with the electron beam, or in the
25 backward region with the RF counter-propagating with the

1 electron beam according to figure 2. Using combinations of
2 the structure described herein, amplifiers and oscillators
3 using forward or backward mode suitable for sub-millimeter
4 RF waves may be formed.